(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(54) Title: BIT LEVEL DIVERSITY COMBINING FOR COFD SYSTEM
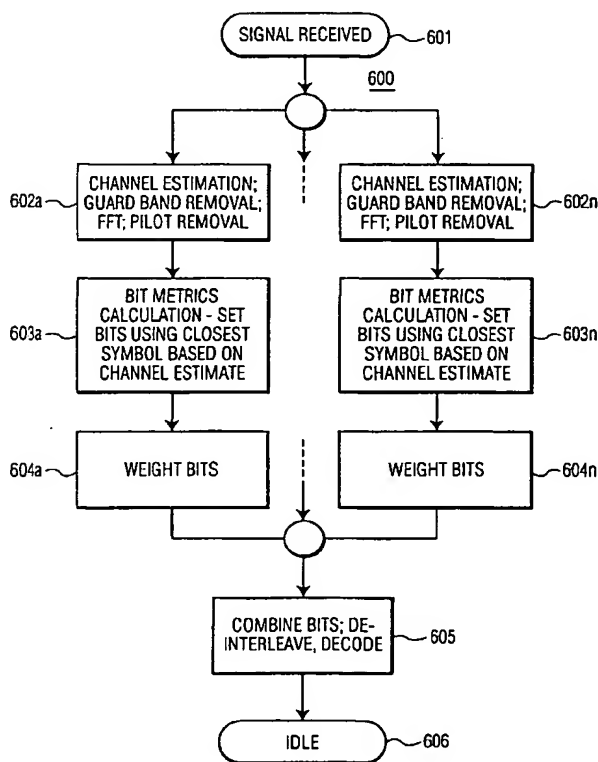
(57) Abstract: Bit level, rather than symbol level, diversity combining is employed within a wireless communications receiver. Channel estimates and bit metrics are separately computed for signals received by different antenna elements. Bit metrics are calculated by determining a least squares cumulative difference between all bits within the received symbol and corresponding bits within constellation symbols as modified by the channel estimate. The separately-determined bit metrics are then combined for decoding. Performance improvements over both single antenna systems and multiple antenna systems with symbol level diversity combining are achieved.

WO 03/050993 A1

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Bit level diversity combining for COFD system

The present invention is directed, in general, to wireless communications and, more specifically, to antenna diversity combining in reception of wireless communications.

5   Currently available commercial wireless communications devices generally all utilize a single antenna for reception. Currently proposed wireless local area network (WLAN) standards, such as the Institute for Electrical and Electronic Engineers (IEEE) 802.11a and European Telecommunications Standards Institute (ETSI) High Performance European Radio Local Area Network version 2 (HiperLAN2) standards, suggest antenna

10   switching and diversity combining techniques to overcome typical channel fading problems in wireless systems. The antenna switching techniques normally select a signal from among various antenna based on the criteria of signal amplitude, while diversity combining utilizes the signals from each antenna by applying different weights. At least in theory, diversity combining produces better results than switching systems.

15   However, all currently published proposals for diversity combining or beamforming for coded orthogonal frequency division multiplexing (COFDM) systems employ algorithms operating at the symbol level, which fails to take maximum advantage of one of the most important benefits of COFDM signaling: that equalization is embedded in the decoding process.

20   There is, therefore, a need in the art for bit-level diversity combining for coded orthogonal frequency division multiplexing receivers.

To address the above-discussed deficiencies of the prior art, it is a primary

25   object of the present invention to provide, for use in wireless communications receiver, use of bit level, rather than symbol level, diversity combining. Channel estimates and bit metrics are separately computed for signals received by different antenna elements. Bit metrics are calculated by determining a least squares cumulative difference between all bits within the received symbol and corresponding bits within constellation symbols as modified by the

channel estimate. The separately-determined bit metrics are then combined for decoding. Performance improvements over both single antenna systems and multiple antenna systems with symbol level diversity combining are achieved.

The foregoing has outlined rather broadly the features and technical

5   advantages of the present invention so that those skilled in the art may better understand the detailed description of the invention that follows. Additional features and advantages of the invention will be described hereinafter that form the subject of the claims of the invention. Those skilled in the art will appreciate that they may readily use the conception and the specific embodiment disclosed as a basis for modifying or designing other structures for

10   carrying out the same purposes of the present invention. Those skilled in the art will also realize that such equivalent constructions do not depart from the spirit and scope of the invention in its broadest form.

Before undertaking the DETAILED DESCRIPTION OF THE INVENTION below, it may be advantageous to set forth definitions of certain words or phrases used

15   throughout this patent document: the terms "include" and "comprise," as well as derivatives thereof, mean inclusion without limitation; the term "or" is inclusive, meaning and/or; the phrases "associated with" and "associated therewith," as well as derivatives thereof, may mean to include, be included within, interconnect with, contain, be contained within, connect to or with, couple to or with, be communicable with, cooperate with, interleave, juxtapose, be

20   proximate to, be bound to or with, have, have a property of, or the like; and the term "controller" means any device, system or part thereof that controls at least one operation, whether such a device is implemented in hardware, firmware, software or some combination of at least two of the same. It should be noted that the functionality associated with any particular controller may be centralized or distributed, whether locally or remotely.

25   Definitions for certain words and phrases are provided throughout this patent document, and those of ordinary skill in the art will understand that such definitions apply in many, if not most, instances to prior as well as future uses of such defined words and phrases.

30   For a more complete understanding of the present invention, and the advantages thereof, reference is now made to the following descriptions taken in conjunction with the accompanying drawings, wherein like numbers designate like objects, and in which:

Fig. 1 depicts a wireless communications system employing bit-level diversity combining according to one embodiment of the present invention;

Fig. 2 is a comparative diagram of a portion of a possible wireless receiver employing symbol-level diversity combining;

Figs. 3, 4A-4D and 5A-5D illustrate a simulation input and comparative results for bit level diversity combining within a wireless receiver according to one embodiment of the present invention; and

Fig. 6 is a high level flow chart for a process of bit level diversity combining according to one embodiment of the present invention.

Figs. 1 and 3 through 6, discussed below, and the various embodiments used to describe the principles of the present invention in this patent document are by way of illustration only and should not be construed in any way to limit the scope of the invention. Those skilled in the art will understand that the principles of the present invention may be implemented in any suitably arranged device.

Fig. 1 depicts a wireless communications system employing bit-level diversity combining according to one embodiment of the present invention. Wireless communications system 100 includes a transmitter 101 and receiver 102 coupled by a wireless transmission channel 103. To achieve reliable high-speed transmission, the wireless transmission channel 103 should be stable with very little fading. While the presence of such a channel is assumed by the IEEE 802.11a and HiperLAN2 standards, in reality the wireless channel 103 has a very high probability of exhibiting Rayleigh fading, either temporal, frequency-selective, or both. High speed transmission under such conditions is very difficult to achieve without increasing the signal processing complexity on the receiver side.

In the exemplary embodiment, transmitter 101 includes a unit 104 for generating and/or buffering the data bits to be transmitted, serially connected to a scrambling unit 105, a convolution coder 106 (with optionally puncturing), a bit interleaving unit 107, a pilot addition unit 108, an inverse fast Fourier transform (IFFT) unit 109, and a guard band addition unit 110.

Transmitter 101 transmits the output of guard band addition unit 110 on wireless channel 103. Receiver 102 employs multiple antenna elements (not shown), with optional tuning to different frequencies, to improve reception in situations where the antenna elements do not experience fading at the same time or frequency.

Within receiver 102, separate processing paths 111a and 111b are maintained for the signals received on different antenna elements. Although only two paths (and

corresponding antenna elements) are illustrated in the exemplary embodiment, any integer number of antenna elements and respective processing paths may be employed.

Each signal processing path 111a and 111b within receiver 102 includes a channel estimation unit 112a, 112b serially connected with a guard band removal unit 113a, 113b, a fast Fourier transform (FFT) unit 114a, 114b for converting the received time domain signal samples into the frequency domain, a pilot removal unit 115a, 115b, a bit metrics calculation unit 116a, 116b, and channel weighting units (C1 and C2) 117a, 117b.

Within signal processing paths 111a, 111b, bit metrics calculation units 116a and 116b utilize the characteristics of bit interleaving under COFDM standards to perform symbol to bit mapping before de-interleaving in the soft decoding by calculating the bit metrics according to the largest probability for each bit using the received symbol. The faded, noisy received version of the transmitted channel symbol is passed through bit metric computation units 116a and 116b, which calculate:

$$m_i^c(n) = -\min_{x \in S^c} \|y - hx\|^2, c = 0,1 \qquad (1)$$

where m is the metric for bit i in one symbol, y is the received symbol, h is the fading and noisy channel (based on the channel estimate), x is the original symbol constellation, and c represents the transmitted bits to be "0" or "1". In physical terms, equation (1) determines the shortest distance between the received symbol and projections of the constellation symbols in the channel.

The bit patterns determined by bit metrics computation units 116a and 1166b are then weighted by weighting unit 117a and 117b and combined by signal adder 118 before being sent to bit de-interleaving unit 119 and Viterbi decoder 120, then to descrambling unit 121 for determination of the data bits stored and/or utilized by unit 122 and employed for bit error rate (BER) calculation in unit 123.

Fig. 2 is a comparative diagram of a portion of a possible wireless receiver employing symbol-level diversity combining. With a symbol-level diversity combining system 200, the signals received by various antenna elements by separate processing paths 201a, 201b including units for channel estimation 202a, 202b, guard band removal 203a, 203b, fast Fourier transform 204a, 204b, and weighting 205a and 205b. However, signal adder 206 combines the processed signals at the symbol level prior to pilot removal 207 and symbol to bit mapping 208.

Figs. 3, 4A-4D and 5A-5D illustrate a simulation input and comparative results for bit level diversity combining within a wireless receiver according to one

embodiment of the present invention. Simulations for the purpose of comparing the performance of (1) single antenna versus dual antenna systems employing bit level diversity combining and (2) dual antenna system employing bit level rather than symbol level diversity combining were performed utilizing the roughly one million data bits grouped in 250 packets

5   with 4096 bits in each packet. Multipath channel characteristics were assumed not to change during transmission of a given packet, while different packets could potentially experience different multipath channel characteristics. The amplitude for the channel during transmission of the packets is illustrated in Fig. 3.

Figs. 4A through 4D depict comparative simulation results for bit error rates

10   (BER) as a function of signal to noise ratio (SNR) for various modulation techniques utilizing a single antenna system versus a dual antenna system with bit level diversity combining. Fig. 4A illustrates the results for rate 1/2 and rate 3/4 binary phase shift key (BPSK) modulation; Fig. 4B illustrates the results for rate 1/2 and rate 3/4 quadrature phase shift key (QPSK) modulation; Fig. 4C illustrates the results for rate 1/2 and rate 3/4 quadrature

15   amplitude modulation with sixteen discrete levels (16-QAM); and Fig. 4D illustrates the results for rate 2/3 and rate 3/4 quadrature amplitude modulation with sixty-four discrete levels (64-QAM).

In the simulation results, the dual antenna system with bit level diversity combining exhibits a substantial performance gain--about 4-6 decibels (dB) better--over the

20   single antenna system. The performance gap between single antenna and dual antenna with bit level diversity combining increases with the signal to noise ratio since better channel estimation is provided by the dual antenna system at higher signal to noise rations.

Figs. 5A through 5D depict comparative simulation results for BER as a function of SNR for various modulation techniques utilizing dual antenna systems, one

25   employing symbol level diversity combining and one employing bit level diversity combining. Fig. 5A illustrates the results for rate 1/2 and rate 3/4 BPSK modulation; Fig. 5B illustrates the results for rate 1/2 and rate 3/4 QPSK modulation; Fig. 5C illustrates the results for rate 1/2 and rate 3/4 16-QAM; and Fig. 5D illustrates the results for rate 2/3 and rate 3/4 64-QAM. The bit level diversity combining system has a significantly better performance--

30   about 2-5 dB better--than the symbol level diversity combining system.

Fig. 6 is a high level flow chart for a process of bit level diversity combining according to one embodiment of the present invention. The process 600 begins with a signal being received at n antenna elements (step 601), where n is any positive non-zero integer. The received signals at each antenna element are separately and concurrently processed for

channel estimation, guard band removal, Fourier transform, and pilot removal (steps 602a-602n). Bit metrics are then independently calculated for each stream by determining, for all bits within a particular symbol, a least squares difference between bits of the received symbol and bits for each constellation symbol after modification with the channel estimate (steps

5   603a-603n). The bits or symbols are then optionally weighted (steps 604a-604n) and combined, deinterleaved, and decoded (step 605). The process then becomes idle (step 606) until additional wireless signals are received.

The unique interleaving and coding characteristics of COFDM systems are considered and exploited in the present invention by employing bit level diversity combining

10   together with combined equalization and decoding within a single wireless receiver stage. Channel estimation and bit metrics calculation for soft Viterbi decoding are performed separately for each antenna element, which experience different channel characteristics. The separate bit metrics are then combined prior to be sent to the Viterbi decoder, producing a performance improvement over both single antenna systems and dual antenna systems

15   utilizing symbol level diversity combining.

It is important to note that while the present invention has been described in the context of a fully functional system, those skilled in the art will appreciate that at least portions of the mechanism of the present invention are capable of being distributed in the form of a machine usable medium containing instructions in a variety of forms, and that the

20   present invention applies equally regardless of the particular type of signal bearing medium utilized to actually carry out the distribution. Examples of machine usable mediums include: nonvolatile, hard-coded type mediums such as read only memories (ROMs) or erasable, electrically programmable read only memories (EEPROMs), recordable type mediums such as floppy disks, hard disk drives and compact disc read only memories (CD-ROMs) or digital

25   versatile discs (DVDs), and transmission type mediums such as digital and analog communication links.

Although the present invention has been described in detail, those skilled in the art will understand that various changes, substitutions, variations, enhancements, nuances, gradations, lesser forms, alterations, revisions, improvements and knock-offs of the invention

30   disclosed herein may be made without departing from the spirit and scope of the invention in its broadest form.

CLAIMS:

1.   A wireless receiver 102 comprising:

            for each of a plurality of antenna elements employed to receive a wireless
signal, separate channel estimation units 112a, 112b and bit metric calculation units 116a,
116b, wherein each bit metric calculation unit 116a, 116b determines bits for each received
symbol from a corresponding antenna element based on a corresponding channel estimate;

            a signal combiner 118 combining outputs of the separate bit metric calculation
units 116a, 116b; and

            a decoder 120 receiving and operating on an output of the signal combiner
118.

2.   The wireless receiver 102 according to claim 1, wherein the bit metric
calculation units 116a, 116b determine a shortest distance between each received symbol and
projected constellation symbols within a channel for the corresponding antenna element.

3.   The wireless receiver 102 according to claim 1, wherein the bit metric
calculation units 116a, 116b determine, for all bits within a received symbol, a cumulative
least squares difference between bits within the received symbol and counterpart bits within
constellation symbols modified by the corresponding channel estimate.

4.   The wireless receiver 102 according to claim 3, wherein the bit metric
calculation units 116a, 116b selectively set bits within each received symbol to a logical one
or a logical zero based upon the cumulative least squares difference.

5.   The wireless receiver 102 according to claim 1, wherein the received wireless
signal is modulated by coded orthogonal frequency division multiplexing.

6.   A wireless communications system 100 comprising:

            a transmitter 101;

a channel 103 by which a wireless signal from the transmitter 101 is transmitted; and

a receiver 102 receiving the wireless signal from the channel, wherein the receiver 102 comprises:

5   - for each of a plurality of antenna elements employed to receive a wireless signal, separate channel estimation units 112a, 112b and bit metric calculation units 116a, 116b, wherein each bit metric calculation unit 116a, 116b determines bits for each received symbol from a corresponding antenna element based on a corresponding channel estimate;

- a signal combiner 118 combining outputs of the separate bit metric

10   calculation units 116a, 116b; and

- a decoder 120 receiving and operating on an output of the signal combiner 118.

7.   The wireless communications system 100 according to claim 6, wherein the

15   bit metric calculation units 116a, 116b determine a shortest distance between each received symbol and projected constellation symbols within a channel for the corresponding antenna element.

8.   The wireless communications system 100 according to claim 6, wherein the

20   bit metric calculation units 116a, 116b determine, for all bits within a received symbol, a cumulative least squares difference between bits within the received symbol and counterpart bits within constellation symbols modified by the corresponding channel estimate.

9.   The wireless communications system 100 according to claim 8, wherein the

25   bit metric calculation units 116a, 116b selectively set bits within each received symbol to a logical one or a logical zero based upon the cumulative least squares difference.

10.   The wireless communications system 100 according to claim 6, wherein the wireless signal is modulated by coded orthogonal frequency division multiplexing.

30

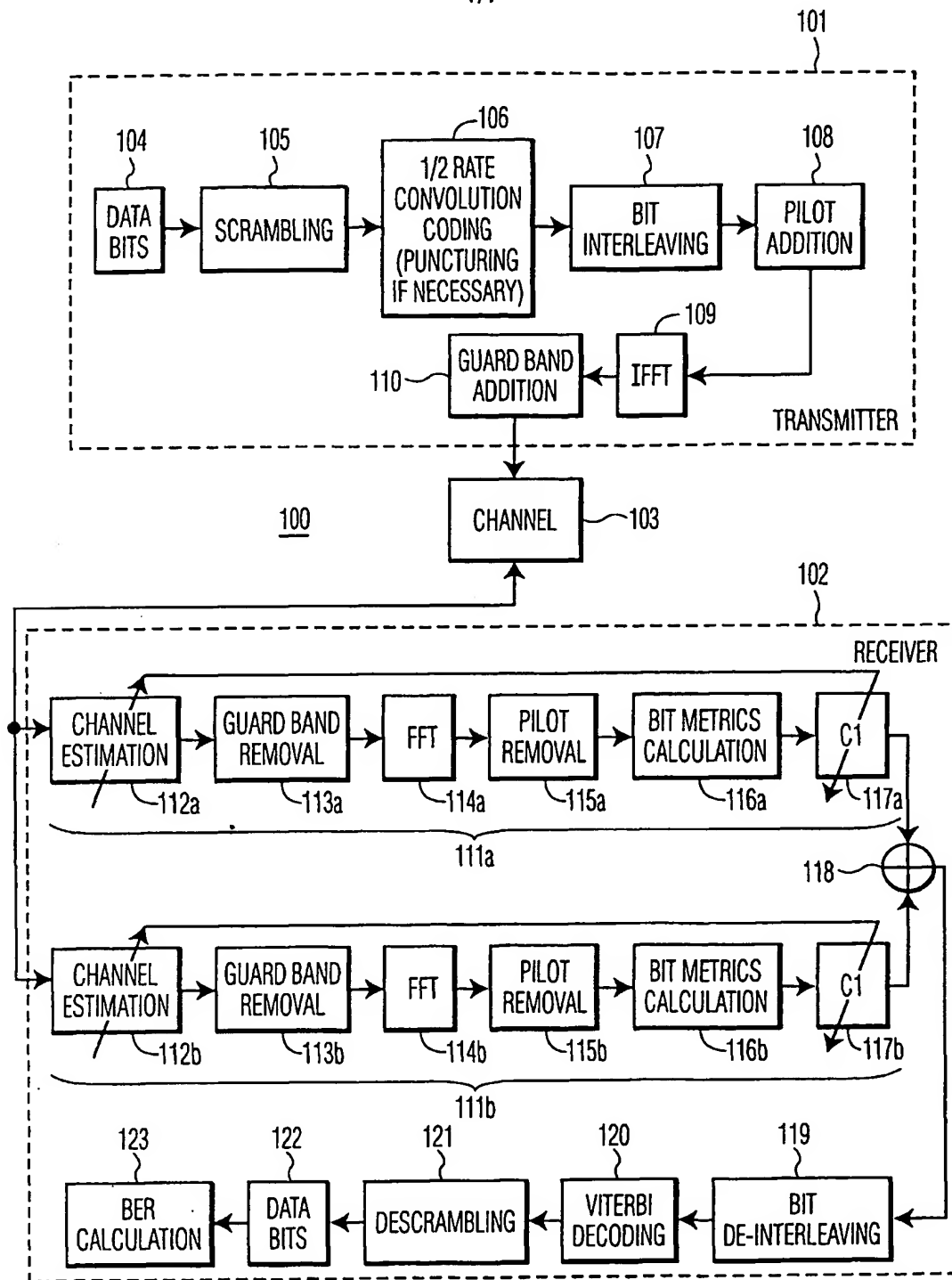11.   A method of receiving a wireless signal comprising:

for each of a plurality of antenna elements employed to receive the wireless signal, separately estimating the channel estimation and calculating bit metrics, wherein each

bit metric calculation determines bits for each received symbol from a corresponding antenna element based on a corresponding channel estimate;

combining outputs of the separate bit metric calculations; and

decoding the combined outputs.

5

12.   The method according to claim 11, wherein the bit metric calculations further comprise:

determining a shortest distance between each received symbol and projected constellation symbols within a channel for the corresponding antenna element.

10

13.   The method according to claim 11, wherein the bit metric calculations further comprise:

determining, for all bits within a received symbol, a cumulative least squares difference between bits within the received symbol and counterpart bits within constellation

15   symbols modified by the corresponding channel estimate.

14.   The method according to claim 13, wherein the bit metric calculations further comprise:

selectively setting bits within each received symbol to a logical one or a

20   logical zero based upon the cumulative least squares difference.

15.   The method according to claim 11, further comprising:

demodulating the received wireless signal using coded orthogonal frequency division multiplexing.

25

16.   A partially processed wireless signal comprising:

separate bit metrics for each of a plurality of antenna elements employed to receive a wireless signal, wherein each bit metric is derived from bits for each received symbol from a corresponding antenna element based on a corresponding channel estimate for

30   that antenna element.

17.   The partially processed wireless signal according to claim 16, wherein the bit metrics are determined from a shortest distance between each received symbol and projected constellation symbols within a channel for the corresponding antenna element.

18.   The partially processed wireless signal according to claim 16, wherein the bit metrics are determined from a cumulative least squares difference for all bits within a received symbol between bits within the received symbol and counterpart bits within

5   constellation symbols modified by the corresponding channel estimate.

19.   The partially processed wireless signal according to claim 18, wherein the bit metrics comprise bits within each received symbol selectively set to a logical one or a logical zero based upon the cumulative least squares difference.

10

20.   The partially processed wireless signal according to claim 16, wherein the bit metrics correspond to a wireless signal modulated by coded orthogonal frequency division multiplexing.
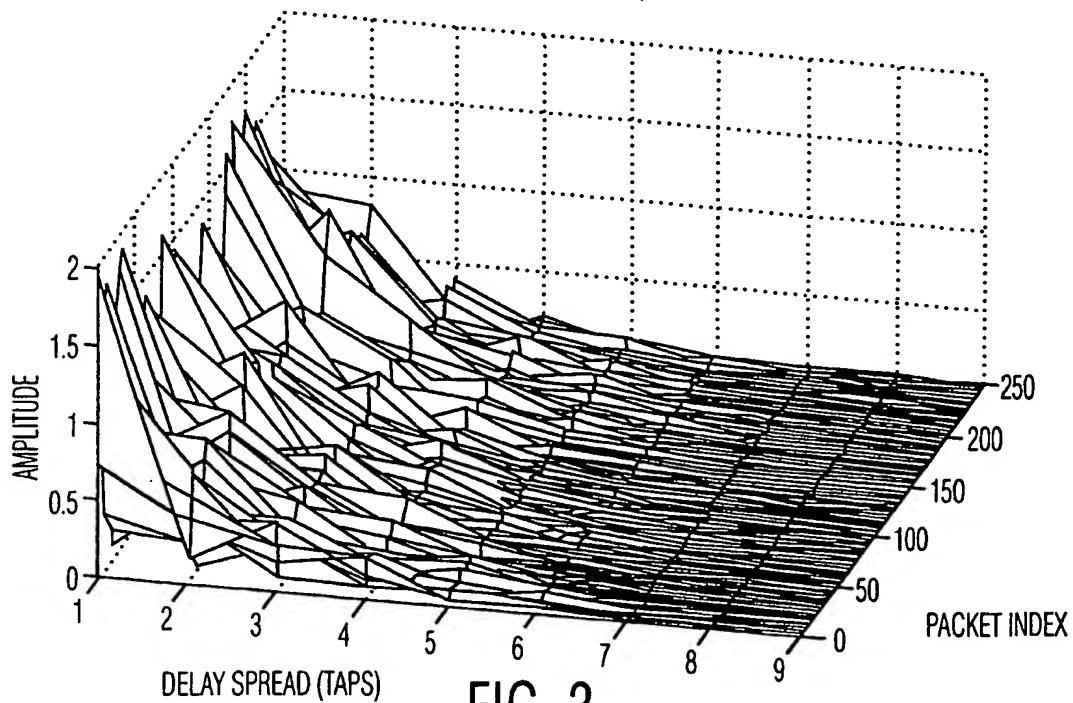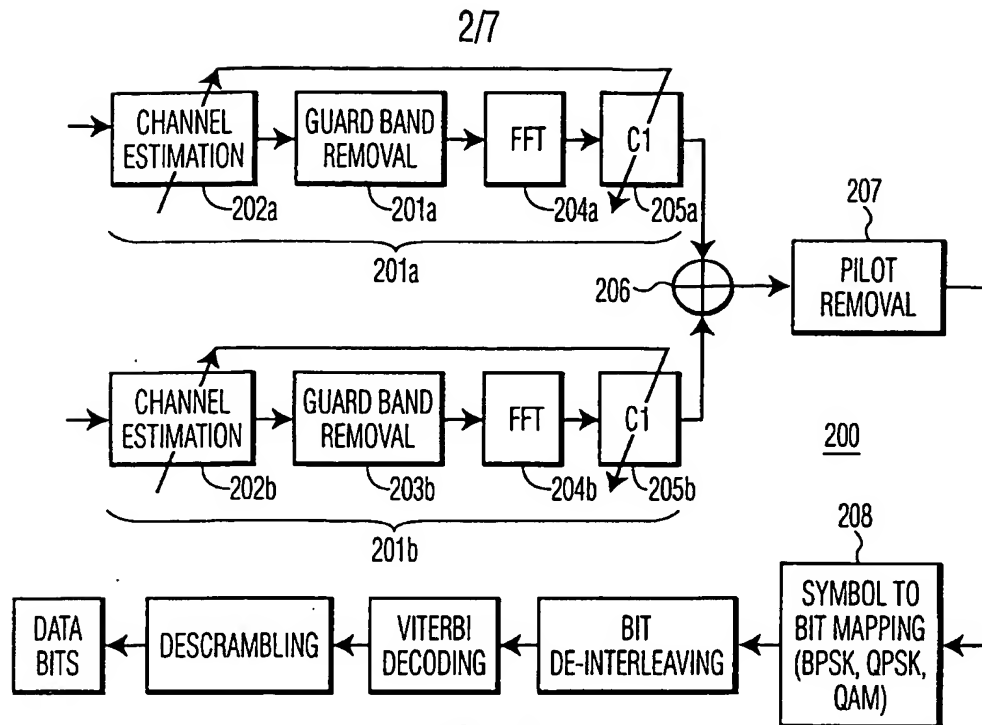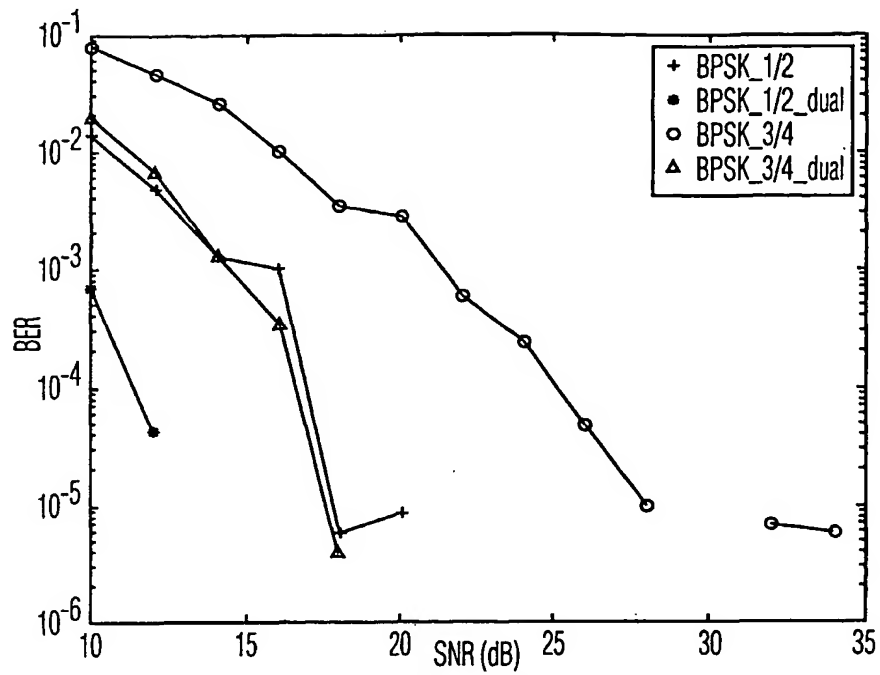
1/7

FIG. 1

CHANNEL ESTIMATION → GUARD BAND REMOVAL → FFT → C1

202a   201a   204a   205a

201a

206 ⊕ → PILOT REMOVAL   207

200

CHANNEL ESTIMATION → GUARD BAND REMOVAL → FFT → C1

202b   203b   204b   205b

201b

208

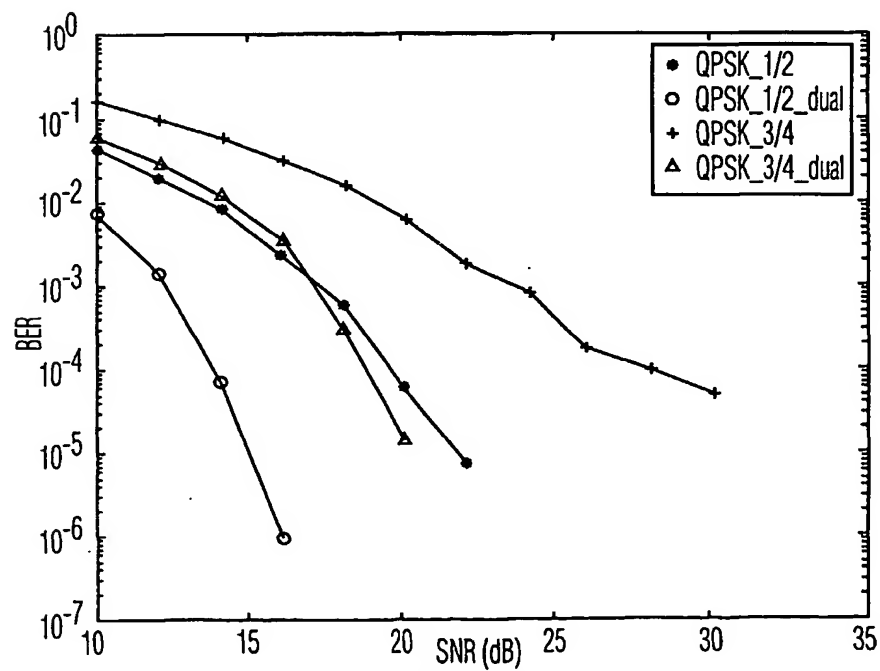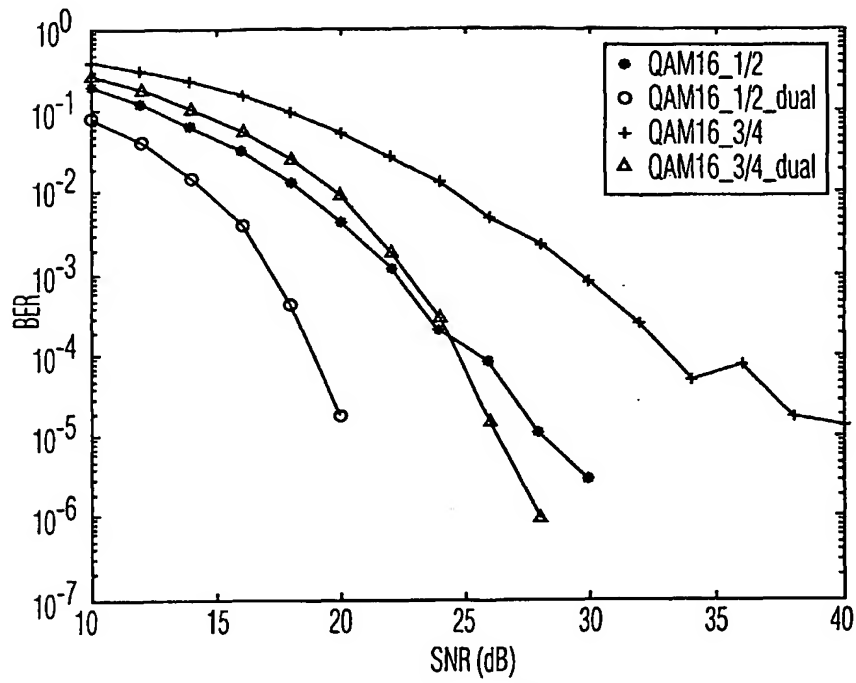DATA BITS ← DESCRAMBLING ← VITERBI DECODING ← BIT DE-INTERLEAVING ← SYMBOL TO BIT MAPPING (BPSK, QPSK, QAM)
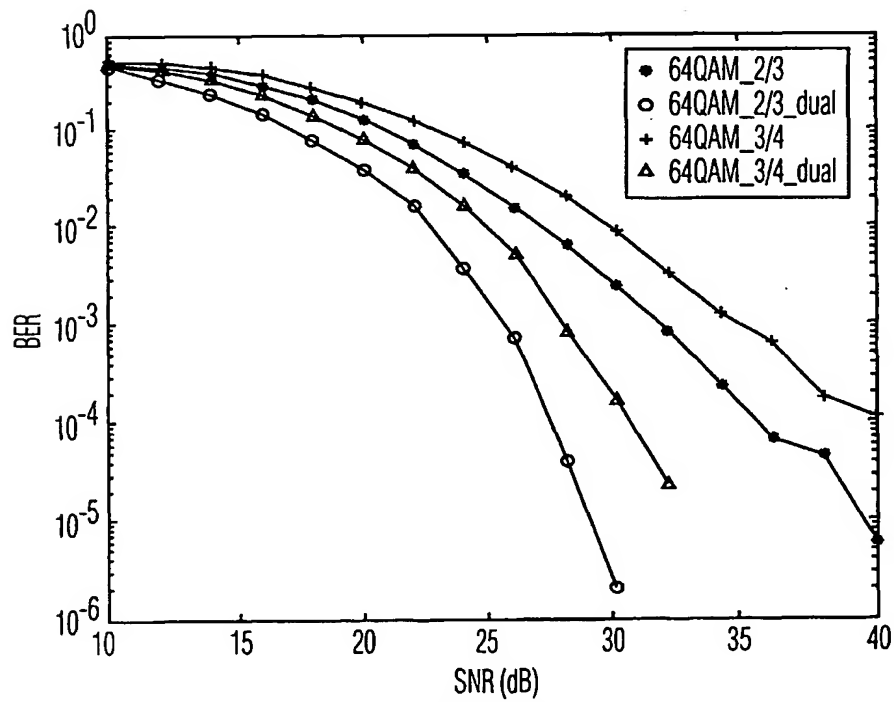
FIG. 2

FIG. 3

FIG. 4A

FIG. 4B

FIG. 4C

FIG. 4D
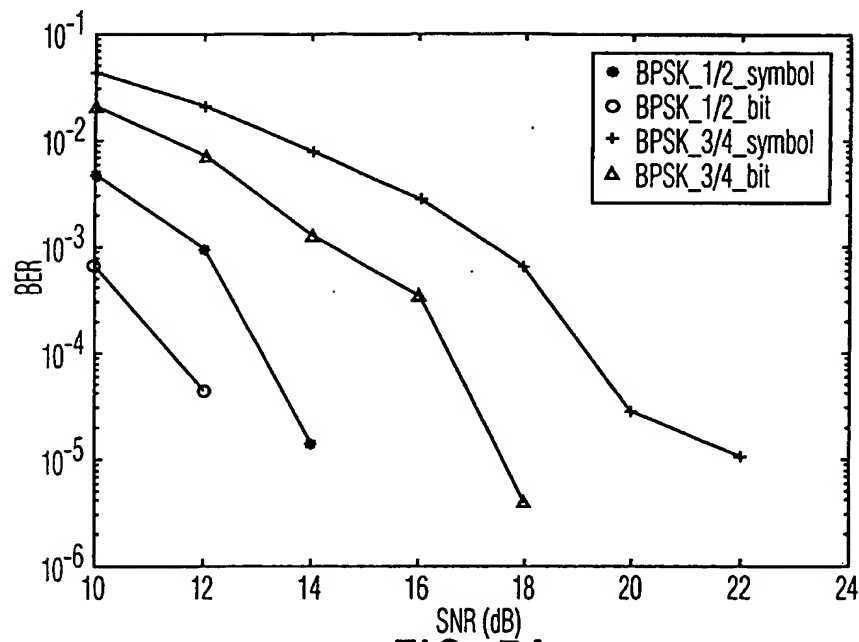
FIG. 5A
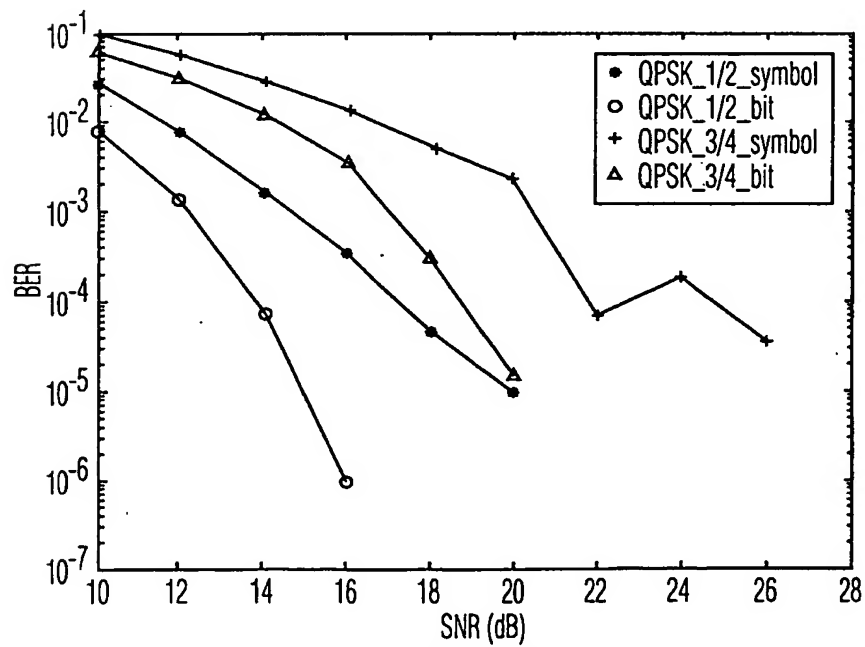
FIG. 5B
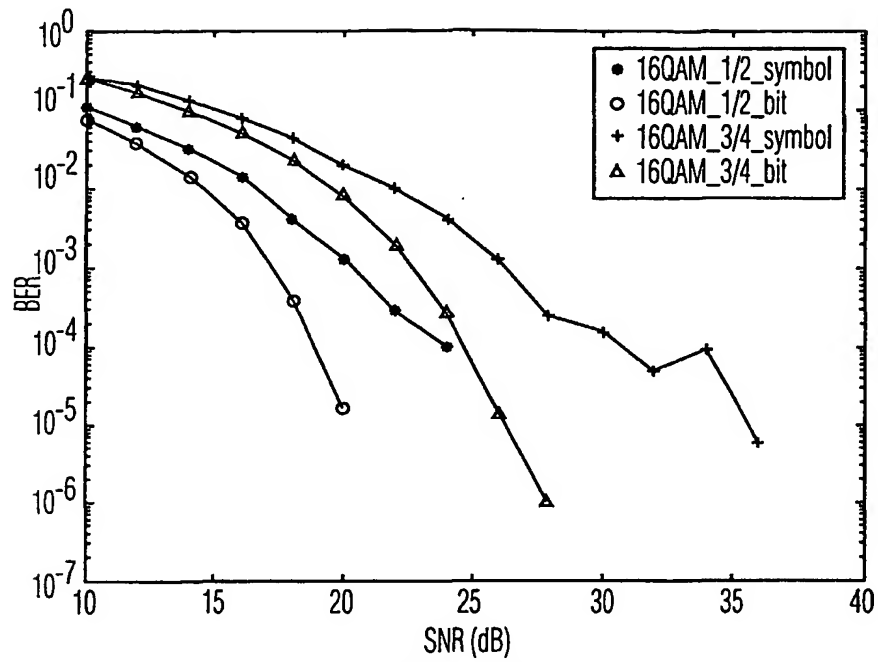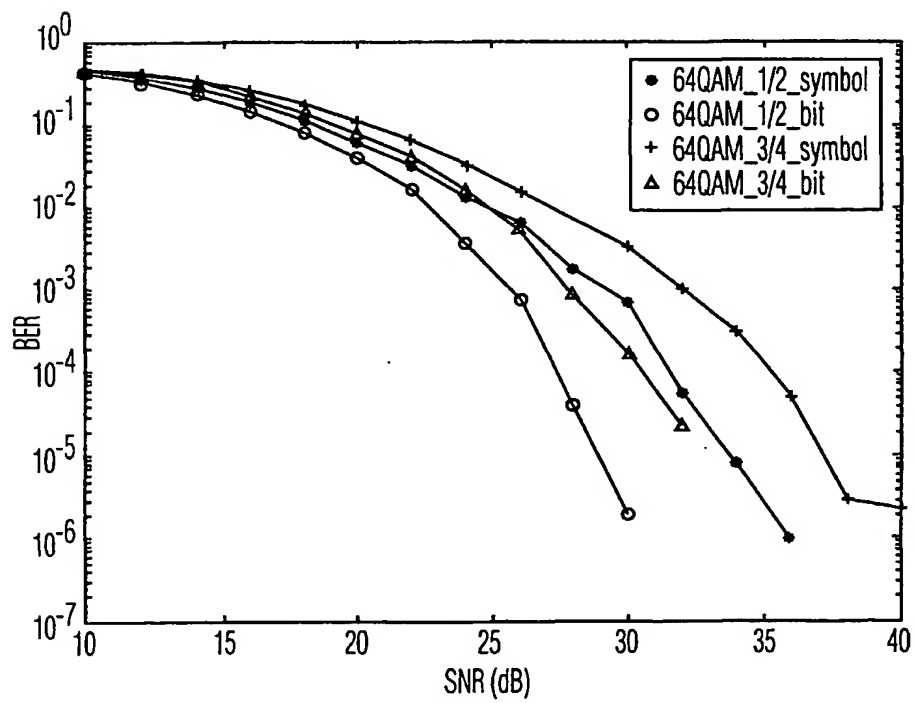
FIG. 5C

FIG. 5D
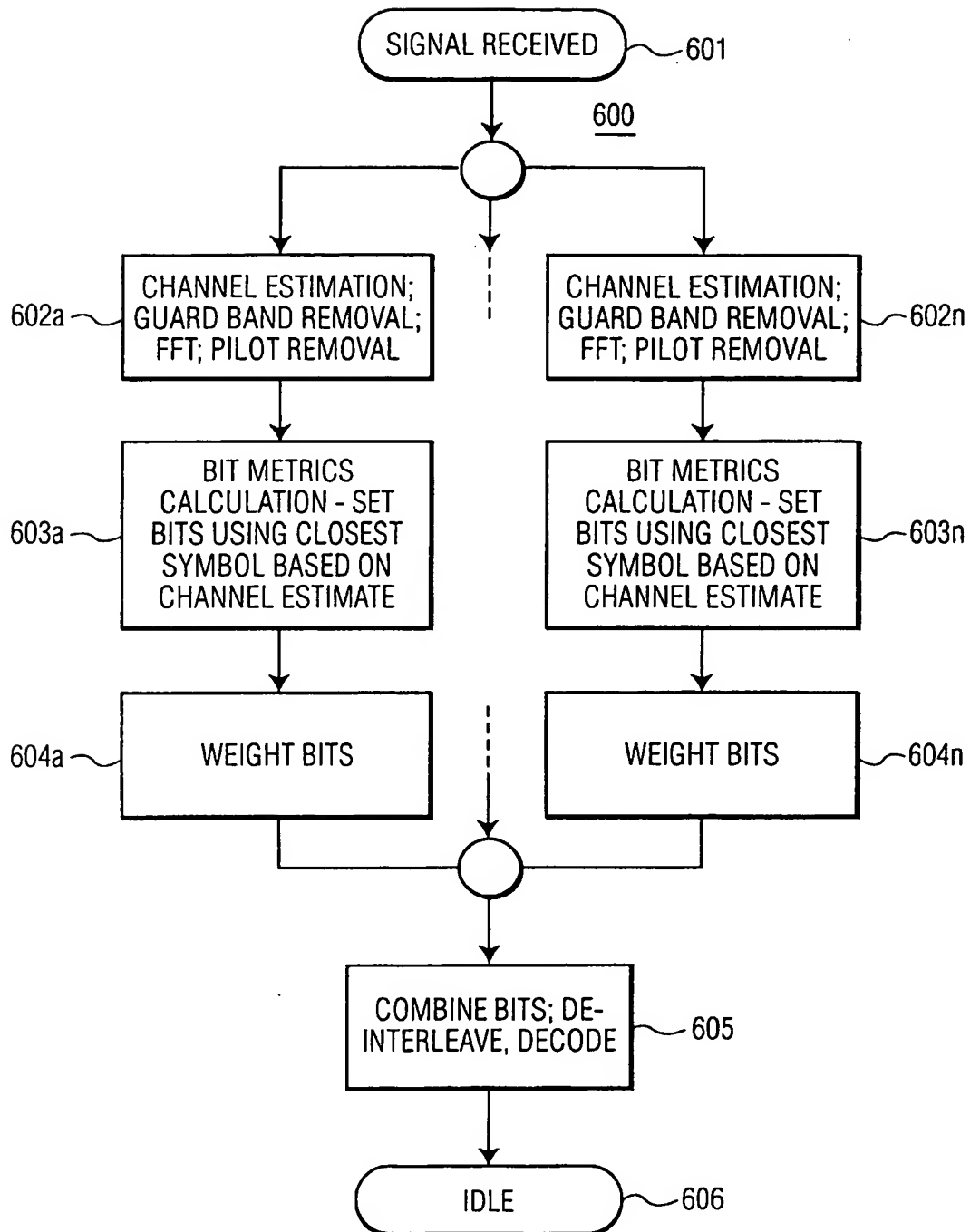
FIG. 6

INTERNATIONAL SEARCH REPORT

A. CLASSIFICATION OF SUBJECT MATTER
IPC 7   H04L1/06   H04B7/00   H04B7/08

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 7   H04L   H04B

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

COMPENDEX, EPO-Internal, INSPEC, PAJ, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	GB 2 355 164 A (CONEXANT SYSTEMS INC ;OAK TECHNOLOGY INC (US)) 11 April 2001 (2001-04-11) abstract figures 3,5 page 6, line 21 –page 7, line 32 page 9, line 23 –page 11, line 13 ---	1-20
X	EP 0 457 460 A (ORBITEL MOBILE COMMUNICATIONS) 21 November 1991 (1991-11-21) figures 3-5 column 2, line 37 –column 3, line 9 column 4, line 8 –column 4, line 37 column 5, line 34 –column 6, line 58 --- -/--	1,5,6, 10,11, 15,16,20

[X] Further documents are listed in the continuation of box C.

[X] Patent family members are listed in annex.

* Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

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"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
29 April 2003	08/05/2003

Name and mailing address of the ISA	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL – 2280 HV Rijswijk Tel. (+31–70) 340–2040, Tx. 31 651 epo nl, Fax: (+31–70) 340–3016	Borges, P

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C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication,where appropriate, of the relevant passages	Relevant to claim No.
X	EP 0 449 327 A (NIPPON ELECTRIC CO) 2 October 1991 (1991-10-02) figures 5,6,8,9	1,5,6, 10,11, 15,16,20

Form PCT/ISA/210 (continuation of second sheet) (July 1992)

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